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Inland Waters Directorate
Western and Northern Region

Direction générale des eaux intérieures
Région de l'ouest et du nord

AQUATIC SENSITIVITY MAPPING

FOR ACID DEPOSITION:

NORTHWEST TERRITORIES, CANADA

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ABSTRACT

In 1981, the Technical Committee on Western Canada Long Range Transport of Atmospheric Pollutants noted the need for a mapping program consistent with studies already completed for eastern Canada that would examine the sensitivity of soils, geology, and surface waters to acidic deposition. Presented here, as part of that mapping program, are three maps representing the sensitivity of surface waters in the Northwest Territories based on alkalinity, calcium content, and pH. These maps can be said to be representative of general patterns only, since there are limitations in the procedure that must be considered, such as sparsity and scarcity of data, variability in measurement techniques, and limitations in the mapping procedure. Nevertheless, they show that although the District of Keewatin and large portions of the eastern half of the District of Mackenzie east of Great Bear and Great Slave Lakes are highly sensitive to acidic precipitation, no significant acidification appears to have taken place as of yet.

Résumé

En 1981 le Comité technique sur le transport à grande distance des polluants atmosphériques dans l'Ouest canadien a souligné la nécessité d'un programme de cartographie conforme aux études déjà complétées au Canada oriental et qui examinerait la sensibilité des sols, de la géologie et des eaux de surface aux retombées acides. On présente ici trois cartes dressées dans le cadre de ce programme et qui illustrent la sensibilité des eaux de surface dans les Territoires du Nord-Ouest d'après l'alcalinité, la teneur en calcium et le pH. Ces cartes ne sont représentatives que des configurations générales seulement en raison de limites de la méthode découlant de la rareté et du caractère épars des données, de la variabilité des techniques de mesure et des limites de la méthode de cartographie par exemple. Elles indiquent néanmoins que même si le district de Keewatin et de grandes étendues de la moitié orientale du district de Mackenzie à l'est du Grand lac de l'Ours et du Grand lac des Esclaves sont très sensibles aux précipitations acides, ces régions ne semblent avoir subi jusqu'à maintenant aucune acidification importante.

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1.0 INTRODUCTION

In April, 1981, the Technical Committee on Western Canada Long Range Transport of Atmospheric Pollutants noted the need for a co-ordinated program across the four western provinces and the Yukon and Northwest Territories (NWT) to map the sensitivity of soils, geology and surface waters to acidic precipitation. This would be consistent with similar studies already completed for Ontario, Quebec, and the Maritime provinces.

Two co-ordinating committees were set up to investigate the data bases and criteria for this mapping program. The results of the Co-ordinating Committee on Surface Waters were reported in a technical report completed in February, 1982. The conclusion reached was that, at best, the data were limited for Western Canada, and that the available data were:

1) Generally of unknown quality with respect to the elapsed time between sampling and measurement and the variability in the accuracy of measurement methodologies between and within jurisdictions;

2) Not available in a computer data bank for many areas and not available within a single source;

3) Commonly greater than five years old if adequate spatial coverage was to be provided; and

4) Frequently, representative of only one period in time as opposed to a number of seasons for a number of years (Aquatic Effects Technical Committee, 1982).

The data availability situation for the NWT was much worse than for the provinces. In February, 1984, Environment Canada, Water Quality Branch, Western and Northern Region, in co-operation with the Pollution Control Division, Northwest Territories Renewable Resources, agreed to assemble available data from appropriate sources and then synthesize these data for assessing aquatic sensitivity to acid deposition. After completing this search, it became obvious that a sparsity of data precluded this type of analysis for the High Arctic. The following presentation of aquatic sensitivity maps represents the product of that data search and subsequent mapping for the mainland NWT.

2.0 THE NORTHWEST TERRITORIES

The NWT is often perceived as one of the last frontiers of Canada. Far from industrialized central Canada and isolated from large population centres, many people assume that this environment is largely free from pollution. Apart from future industrialization within the north itself, attention must also be given to addressing possible problems resulting from the long range transport of atmospheric pollutants (LRTAP); especially, the concern over acid deposition resulting from sulphur and nitrogen oxide emissions (SO_2 and NO_x). As the wide ranging effects of both wet and dry acid deposition have become better understood, concern for northern aquatic sensitivity has increased.

A major source of acid deposition in Canada's north has been suspected to be from the Soviet Union with some contribution from the industrial heartland of eastern North America (Sub-Committee on Acid Rain, 1981). Acidic materials are transported to the north and during the winter and spring months may remain suspended as particulates in the atmosphere (Sub-Committee on Acid Rain, 1981; Persson et. al., 1982). Total SO_2 emissions originating in the Yukon and Northwest Territories themselves are 17,000 tonnes annually, most of it from Giant Yellowknife gold mine. Since the total emissions for all of western and northern Canada is estimated at 1.6 million tonnes, this represents only slightly more than 1 per cent of this total (Shewchuk, 1983a). This is not expected to change significantly, although any new large emitter could alter projections considerably.

Other sources of acid deposition in the NWT, especially near the border with Saskatchewan, are the Alberta oil sands projects. These developments have the potential to expand quite rapidly once the world oil price justifies it. Though the oil sands themselves are located in an area with a relatively high buffering capacity, the real concerns are east and northeast of the plants in the Precambrian Shield area in northern Saskatchewan and in the southern NWT. Less than 2 per cent of the total sulphur dioxides and nitrogen oxides originating from the oil sands are deposited within 25 kilometers of the source. The remaining 98 per cent of the emissions go beyond to ecosystems that are much more susceptible than those in the calcareous land areas of Alberta

(Hammer, 1980). Since oil sands emissions were estimated in 1983 to include 107,000 tonnes of sulphur dioxide and 50,000 tonnes of nitrogen oxide (Shewchuk, 1983a), an amount significantly more than what originates in the Northwest Territories may reach its boundaries.

A study commissioned by the Alberta Oil Sands Environmental Research Program on air trajectories from the oil sands region shows that air originating there can penetrate as far north into the NWT as the islands. South and east of Great Slave Lake, air parcels from the oil sands region move through the region about once a week on average. Further north and west, the frequency decreases, but most of the mainland east of the Mackenzie River could be said to be influenced by these air masses (Denison, 1977; from Shewchuk, 1983a).

Manitoba has the highest SO_2 emissions in western Canada with mines and smelters at Thompson and Flin Flon (Sub-Committee on Acid Rain, 1981). These smelters are not considered a great threat to the NWT since winds are mostly in an easterly direction. Nevertheless, pollutants from northern Manitoba may penetrate the NWT (Shewchuk, 1983a).

Shewchuk (1983a) reports that acidic deposition in the NWT is primarily episodic in nature and determined by season and air mass trajectory. Since precipitation scavenging processes are more efficient in the summer than in the colder winter (Shewchuk, 1983b; Hammer, 1980), most of the aerosols remain in suspension for long periods during the winter. In the summer, deposition processes remove the air pollutants more quickly in

areas closer to the emission source. In the winter, they are removed less quickly due to a decrease in precipitation, and therefore remain airborne for longer periods of time, allowing for a corresponding increase in travel time and distance.

Since the spring melt period in the north lasts for only a few weeks, all the acidic pollutants built up over the winter would be released very quickly (Shewchuk et. al., 1981; Sub-Committee on Acid Rain, 1981); thus there exists potential for a more severe "acid shock" in the north than would occur in the south.

3.0 AQUATIC SENSITIVITY

Although acid rain has an effect on all parts of the environment, Hammer (1980) states that the most obvious and severe are observed in the aquatic ecosystems. The aquatic chemistry of a surface water body will provide a good measure of its sensitivity, reflecting influencing geological and physical factors as well (Lucas and Cowell, 1982).

Consistent with the recommendations of the Aquatic Effects Technical Committee (1982), the Western LRTAP Committee selected five parameters to provide continuity, at least in intent, with other jurisdictions. The five parameters selected were pH, alkalinity, calcium, magnesium, and aluminum.

Although pH does not really provide any direct indication of aquatic sensitivity, it provides an essential base level, and will of course provide valuable "after-the-fact" information in the event that acidification of surface waters does begin. Coupled with that, it has been the parameter most consistently measured over time, giving a relatively large data base.

Alkalinity represents the carbonate-bicarbonate buffering capacity of a water body. This is the primary source of that water body's ability to absorb acid, and is therefore the most direct measure of sensitivity. The following sensitivity criteria, proposed by the United States-Canada Research Consultation Group (Altshuller and McBean, 1979, from Liaw, 1982) is used in this study:

Sensitivity	Alkalinity (mg/L CaCO3)
Highly Sensitive	0 - 10
Moderately Sensitive	10 - 20
Least Sensitive	>20

Although these divisions are arbitrary to some extent (Harvey et. al., 1981), they do provide a useful index for sensitivity consistent with most other indices found in the literature (Heiskary and Thornton, 1983), and with the other Canadian jurisdictions' sensitivity maps. Further confirmation of the selection of this index is found in Heiskary and Thornton (1983), who, in a study of acid rain sensitivity in Minnesota lakes, found that these alkalinity sensitivity breakpoints corresponded to the critical breakpoints of the calcite saturation index (CSI) as designated by Conroy et. al. (1974).

If the alkalinity is above 20 mg/L as $CaCO_3$, the lake is thought to contain enough buffering capacity to neutralize acidic deposition for an indefinite period of time (Heiskary and Thornton, 1983), and is considered least sensitive. If the alkalinity is below 10 mg/L, this represents a highly sensitive, non-calcareous lake that will become acidified under continued acidic deposition (Shewchuk et. al., 1981). If the value falls between these two values, the lake may be affected in the long term, especially if acidic loadings increase (Heiskary and Thornton, 1983), and it is therefore considered moderately sensitive.

Calcium, and to a lesser extent magnesium, are also good indicators of buffering capacity because they comprise most of the carbonates in the Canadian Shield, and are thus closely related to alkalinity in concentration (Liaw, 1982). Accordingly, the United States-Canada Research Consultation Group also proposed a set of criteria for calcium (Altshuller and McBean, 1979) that corresponded with the alkalinity index:

Sensitivity	Calcium (mg/l)
Highly Sensitive	0 - 4
Moderately Sensitive	4 - 8
Least Sensitive	8

As the acid concentration rises, the solubility of heavy metals rises as well. Aluminum toxicity in particular becomes of concern (Heiskary and Thornton, 1983) and this is one of the reasons why it was chosen as one

of the five parameters. Since aluminum solubility rises rapidly as the pH falls below 5, it provides an indirect assessment of the degree of acidification of a lake, although not really of the sensitivity of the lake where no acidification has occurred (Minnesota Pollution Control Agency, 1981).

4.0 DATA BASE

The primary data source for the NWT was the National Water Quality Data Base (NAQUADAT) maintained by Environment Canada. A copy of all available NWT data for the period 1973 to 1983 was obtained and screened with respect to appropriateness for aquatic sensitivity mapping. The NAQUADAT data base was supplemented with data from research reports, studies, and environmental impact assessments conducted by a variety of government and non-government agencies. Even with this augmentation of data, it soon became obvious that there were insufficient data to include magnesium, and especially aluminum, as mapping parameters.

Table 1 is a categorization of sampling sites in the lakes and streams included in the NWT maps. Although the NWT maps included data from Saskatchewan and Manitoba (Alberta data were not available) in order that the integrity of the contours at the border might be preserved, this table includes only the NWT sampling sites.

Table 1. Summary of Northwest Territories Sampling Sites (1973-1983)

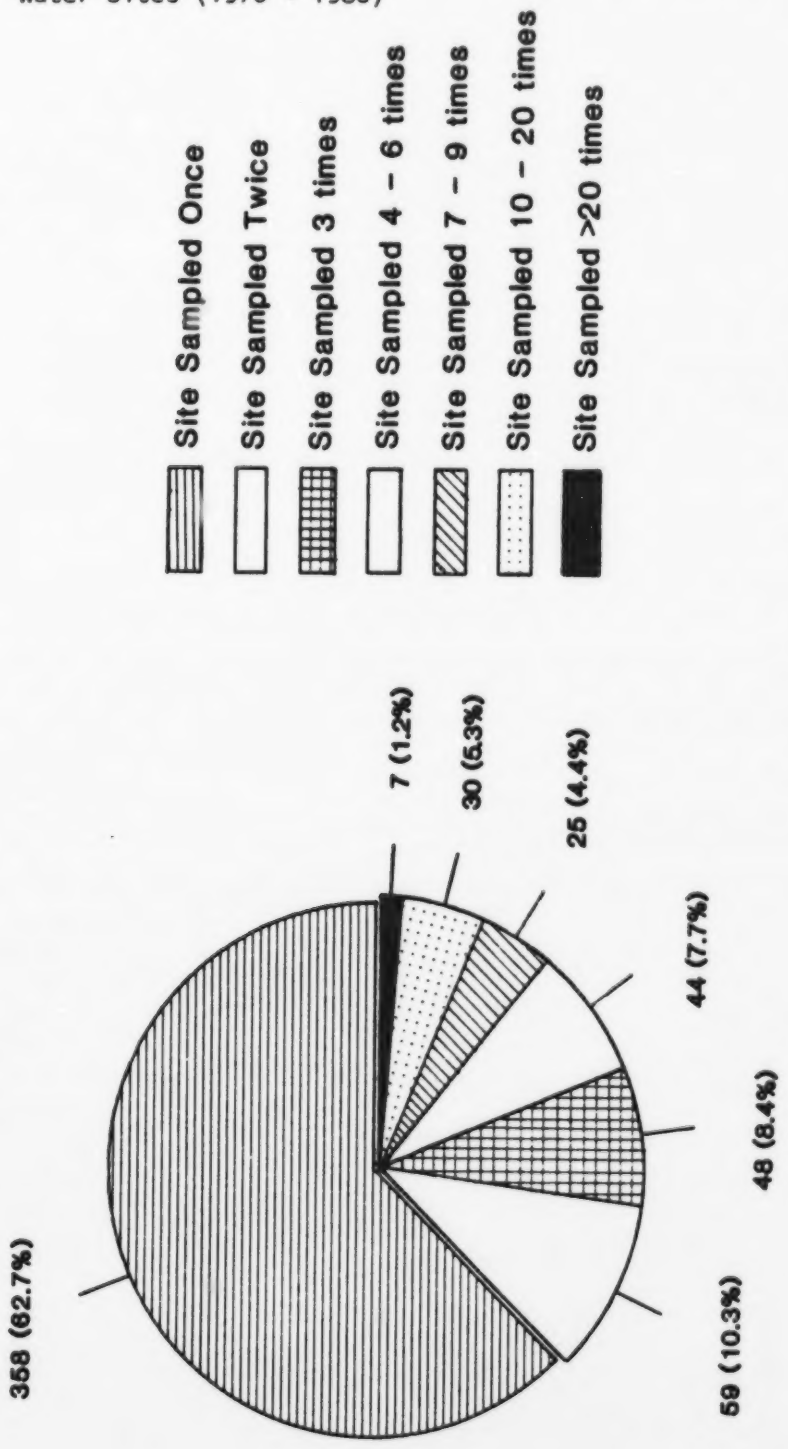
Lakes		Streams	
Lakes with 1 sampling site:	113	Streams with 1 sampling site:	80
Lakes with 2 sampling sites:	15	Streams with 2 sampling sites:	29
Lakes with 3 sampling sites:	4	Streams with 3 sampling sites:	9
Lakes with 7 sampling sites:	1	Streams with 4 sampling sites:	4
Lakes with 11 sampling sites:	1	Streams with 6 sampling sites:	1
Lakes with 13 sampling sites:	1	Streams with 7 sampling sites:	2
		Streams with 8 sampling sites:	1
Total number of Lakes	135	Total number of Streams/Rivers	126

Total number of Lake Sampling Sites	186
Total number of Stream/River Sampling Sites	209
Total number of Unknown River or Lake Sites	176
Total number of Sampling Sites	571

NOTE: The distinction "Unknown River or Lake Sites" refers to waters that have a known geographic location but an unknown name. It is also not known whether these sites are lakes or rivers.

Table 1 indicates the distribution of the number of sites sampled in each type of water body as well as the distribution of sampling site types. It cannot be assumed that lakes or rivers sampled at multiple sites are better characterized than a lake or river that has been sampled at only one site. A unique sampling site within a water body may have been sampled many times. In those cases, it will appear as a water body with only one sampling site, but this site may in fact have had a number of samples taken over a period of time, as illustrated in Figure 1. From Table 1 and Figure 1, it is clear that most water bodies and/or sites were sampled only once. This procedure has not attempted to weight sites on the basis of multiple sampling sites within a given water body or as a result of repeated sampling of a single site.

Figure 1. Sampling Frequency of the 57 Latitude Northwest Territories Water Sites (1973 - 1983)



Although there are 571 sampling sites, not all of the sites were sampled for each of the three mapped parameters (alkalinity, calcium, and pH). Alkalinity was sampled at 420 sites, calcium at 459 sites, and pH at 510 sites of the 571 unique sampling locations (see map). It must also be noted that many of the stations, although having a unique latitude and longitude, occur in clusters, with the result being that wide geographic areas are sparsely represented. June, July, and August were the months in which most of the samples were collected, although all of the months of the year were represented at least once.

A complete listing of the data and sampling site locations is available from the Inland Waters Directorate, Water Quality Branch, Motherwell Building, 1901 Victoria Avenue, Regina, Saskatchewan S4P 3R4.

5.0 MAPPING TECHNIQUE

The aquatic sensitivity map for the NWT was completed with the aid of the General Purpose Contouring Program (GPCP) operating on the CYBER computer, at the Computer Science Centre, Department of Energy, Mines and Resources, in Ottawa (1979).

The first operation performed on the data was the conversion of the location from a value in degrees latitude and longitude, to a value in mapping units in a right-handed Cartesian co-ordinate system, based on a Lambert Conformal Conic Projection map of Canada with origin at 49 00 and 100 00.

Following that, a grid was superimposed on the data, and values at the grid intersections were determined. It is from these grid, or mesh-point values that the contours were drawn (Figure 2). A careful visual inspection of these computer-generated contour maps was completed to eliminate anomalous interpolations and extrapolations.

Figure 2. Illustration of Computer Generated Mapping Procedures

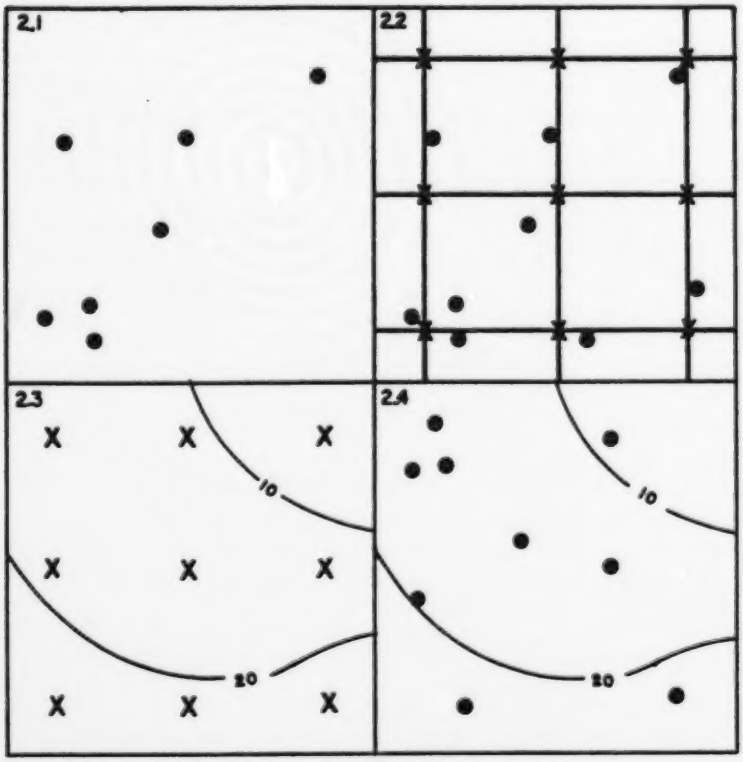


Figure 2.1 The mean value of the data points (●) are entered into the GPCP program and plotted.

Figure 2.2 A user-specified grid is super-imposed on the data and mesh-point values (x) are determined at the intersecting lines from the neighbouring data points.

Figure 2.3 Contours are drawn based on the mesh-point values.

Figure 2.4 The final map will show the original data points and the contours.

6.0 RESULTS AND DISCUSSION

Sensitivity and susceptibility of surface waters to acidification are dependent on the bedrock and type and depth of soil cover as well as the sulphur and nitrogen loadings. Since the Precambrian Shield covers about half of mainland NWT, one would suspect that east of the Mackenzie River, surface waters on the shield would tend to have minimal buffering capacity and therefore would likely be rapidly affected by anthropogenic acidification. The sensitivity maps already completed for the potential of soils and bedrock to reduce acidity derived from atmospheric deposition show the District of Keewatin and the eastern half of the District of Mackenzie to be the most sensitive to acidic precipitation (Lucas, 1985). There are also areas of high sensitivity in the northwest bordering on the Beaufort Sea, but the most obvious division between the area of the lowest sensitivity and the highest sensitivity is along a dividing line from Great Bear Lake in the north to Great Slave Lake.

The aquatic sensitivity maps reflect the major patterns expected from the bedrock geology maps. The maps based on alkalinity and calcium (Maps 1 and 2) show a clear east-west division roughly following the shield line south from Great Bear to Great Slave Lake, with a rapid decrease in sensitivity on both of the maps moving west away from the sensitive bedrock and soil areas. The sensitivity map based on the calcium parameter also shows moderate sensitivity along the northern coastline that is not reflected in the map based on the alkalinity parameter. Although this does provide some consistency with the bedrock-soil

sensitivity in that area, the data available here were limited at best, as pointed out by the map of the sampling site locations.

Despite this vast area of highly sensitive waters, the map for pH (Map 3) shows that there does not yet appear to be any acidification taking place. The area mapped with pH less than 7 indicates a range primarily between 6.3 and 7, with only 5 values recorded below that range. Again, there is a clear dividing line along the shield, with all contours within the shield having values of less than 7.5. This is in contrast to the west, where it is only along the northern coastline (compare with the calcium map) that there are values less than 7.5. Although this is encouraging, it must be kept in mind that the data used are from the last ten years, which could mask current pH conditions of these sensitive areas.

The criteria set out for accepting data as legitimate originally set a five year limit for the age of data, and ideally would have included only values from small headwater lakes. These restrictions were out of the question for the NWT if there was to be a data base of any significant size. The screening procedure therefore included data from the previous decade (beginning with 1973) from lake and river stations generally typifying an area of relatively homogeneous geology. Large lakes and river stations receiving drainage from a geologically heterogeneous basin were excluded.

Since more than just NAQUADAT data were used, it was inevitable that a variety of measurement techniques would be represented, and this becomes another limitation. There is also no way of knowing how large a time gap there was between sample collection and analysis. These limitations are especially important with respect to the pH map. Since pH may be measured both in the laboratory and in the field, it is the parameter most likely to deteriorate over time; and thus, it is also the parameter most likely to show the greatest variability with measurement technique.

The data values used in the preparation of the maps were averaged for each distinct location, and the calculated means at all locations were weighted equally by the computer mapping procedure. Some, however, may have had a substantial amount of information at that site, while others were representative of only a single measurement.

Often the data were clustered in groups while other areas of the NWT may have been quite poorly represented. While the computer plotting program does have some ability to extrapolate data bases into areas where little or no information exists, there are obviously limitations in this capability.

One of the biggest limitations in the computer-generated mapping method, when such a large area is to be mapped, is the specification of the grid size. A large grid size had to be specified in order not to exceed the limits on computer memory. This limitation is especially important when the plot is of an area that does not have an even distribution of data,

such as in this case. This means that the contours drawn are not to be taken as rigid, for slight adjustments in the program could noticeably alter them, especially in areas where there were large data gaps. Thus, these maps represent the general patterns only, and this must be kept in mind when using the maps. Figure 3 illustrates some limitations based on the plotting program that could affect map quality.

7.0 CONCLUSIONS AND RECOMMENDATIONS

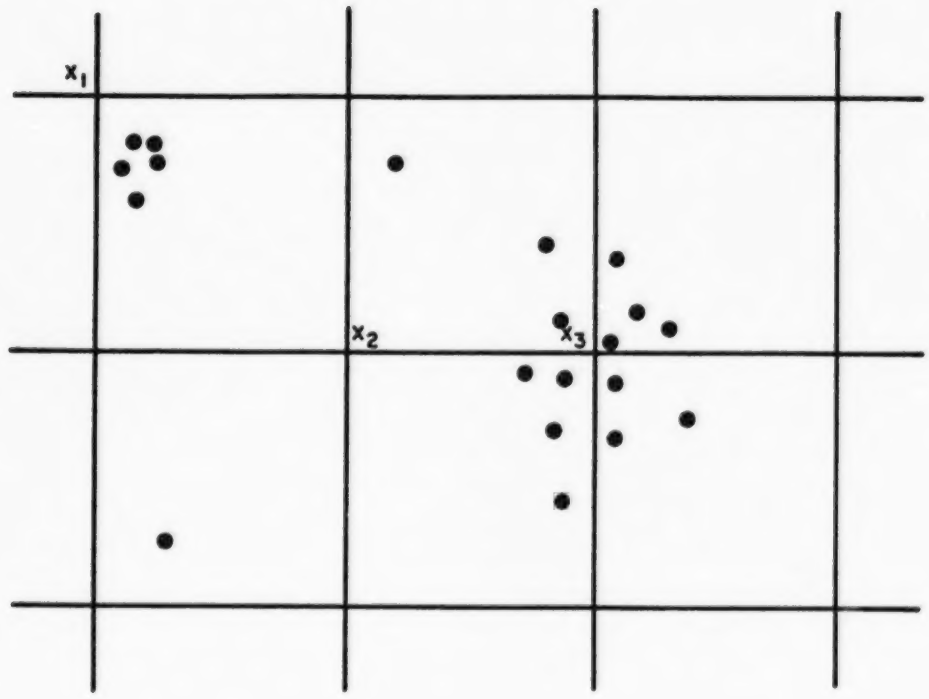
Mapping of available surface water quality data for the NWT indicates that large portions of the District of Keewatin and the eastern half of the District of Mackenzie are highly sensitive to acidification. The pH data, however, do not indicate that these sensitive waters have been affected by acidic deposition. It is not expected that the limitations in the data base (temporal, spatial, and possibly even analytical) greatly affect the general patterns shown on the maps, although they do preclude the forming of definitive statements on the specific boundaries of the sensitive areas.

It is recommended that based on these preliminary maps, combined with the terrestrial sensitivity assessments recently completed for the NWT, that the geographic areas which appear to be highly sensitive be more rigorously defined. Subsequently, a survey approach should be adopted to verify both the terrestrial and aquatic sensitivity as well as to determine the chemical effect of acid deposition on the most sensitive waters. As well, areas which clearly indicate a paucity of data should

also be subjected to surveys of the surface waters for the purpose of defining sensitivity. Areas to be surveyed for this purpose should be ranked on the basis of the sensitivity classification provided by the terrestrial sensitivity mapping. Upon completion of these surveys, periodic monitoring should be established for clusters of stations selected for indicator areas in order to detect any changes resulting from acidic deposition.

This monitoring program should be developed and implemented as resources allow, following the necessary surveys to further define sensitive areas and to augment the data base as required.

Figure 3. Grid Limitations for the Contour Mapping Program



● data point

x mesh point

NOTES:

Near X1, there is a limited amount of clustered data.

Near X2, there is very little data. Since there are more points to the upper left of X2 than to the lower left, for instance, the cumulative effect of these points will be greater than the effect of the lower left point. This would be valid if each point had been sampled the same number of times, but each of the clustered points may only be representative of a single observation while the single point may be a known, reliable value, representative of regular observations over a long period of time.

Near X3, the points are numerous and evenly spaced and will give a good representative number for the mesh-point. With a smaller grid size, these numerous data points would not have to be condensed into a single point at X3.

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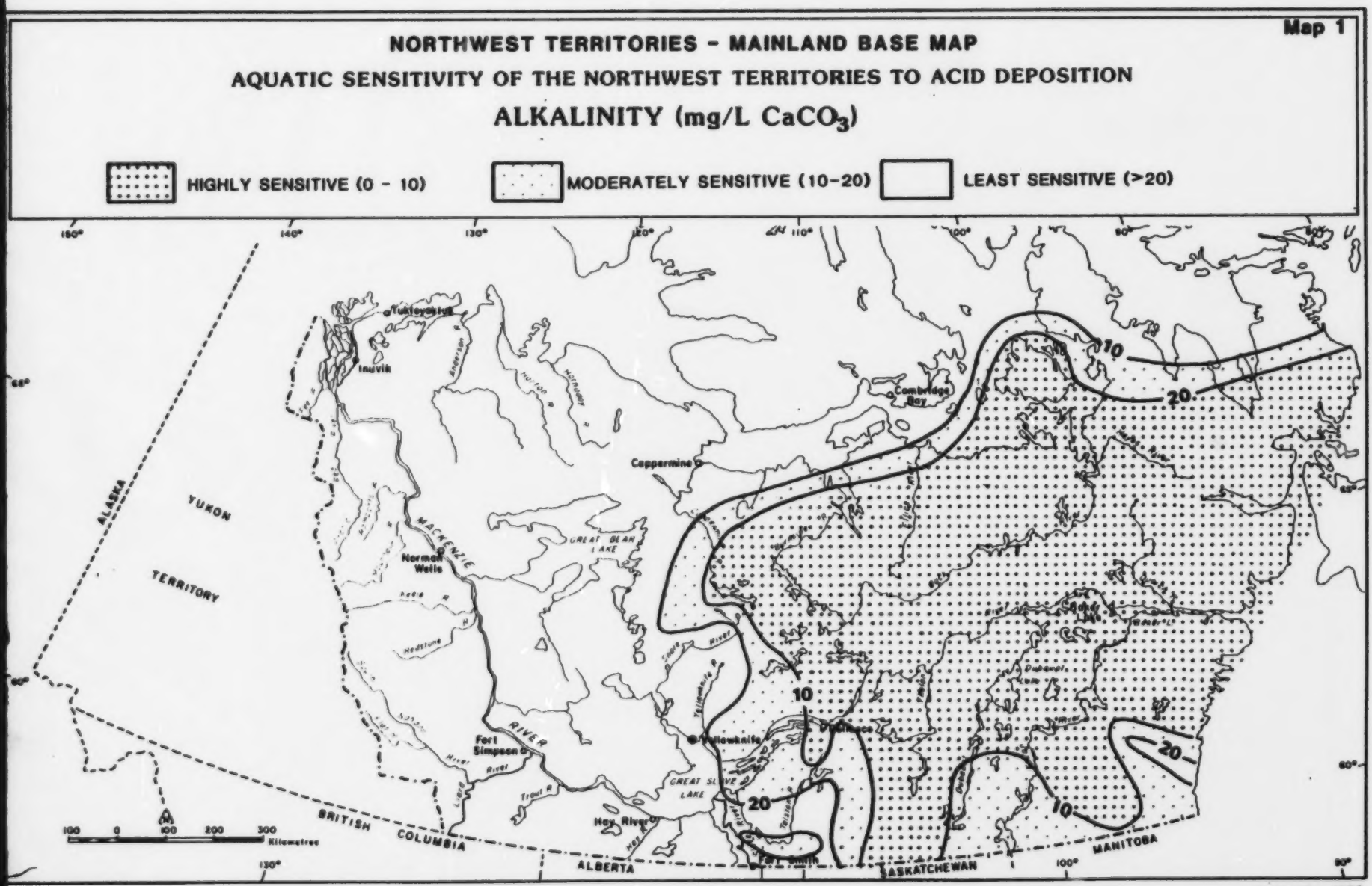
Map 1

NORTHWEST TERRITORIES - MAINLAND BASE MAP

AQUATIC SENSITIVITY OF THE NORTHWEST TERRITORIES TO ACID DEPOSITION

ALKALINITY (mg/L $CaCO_3$)



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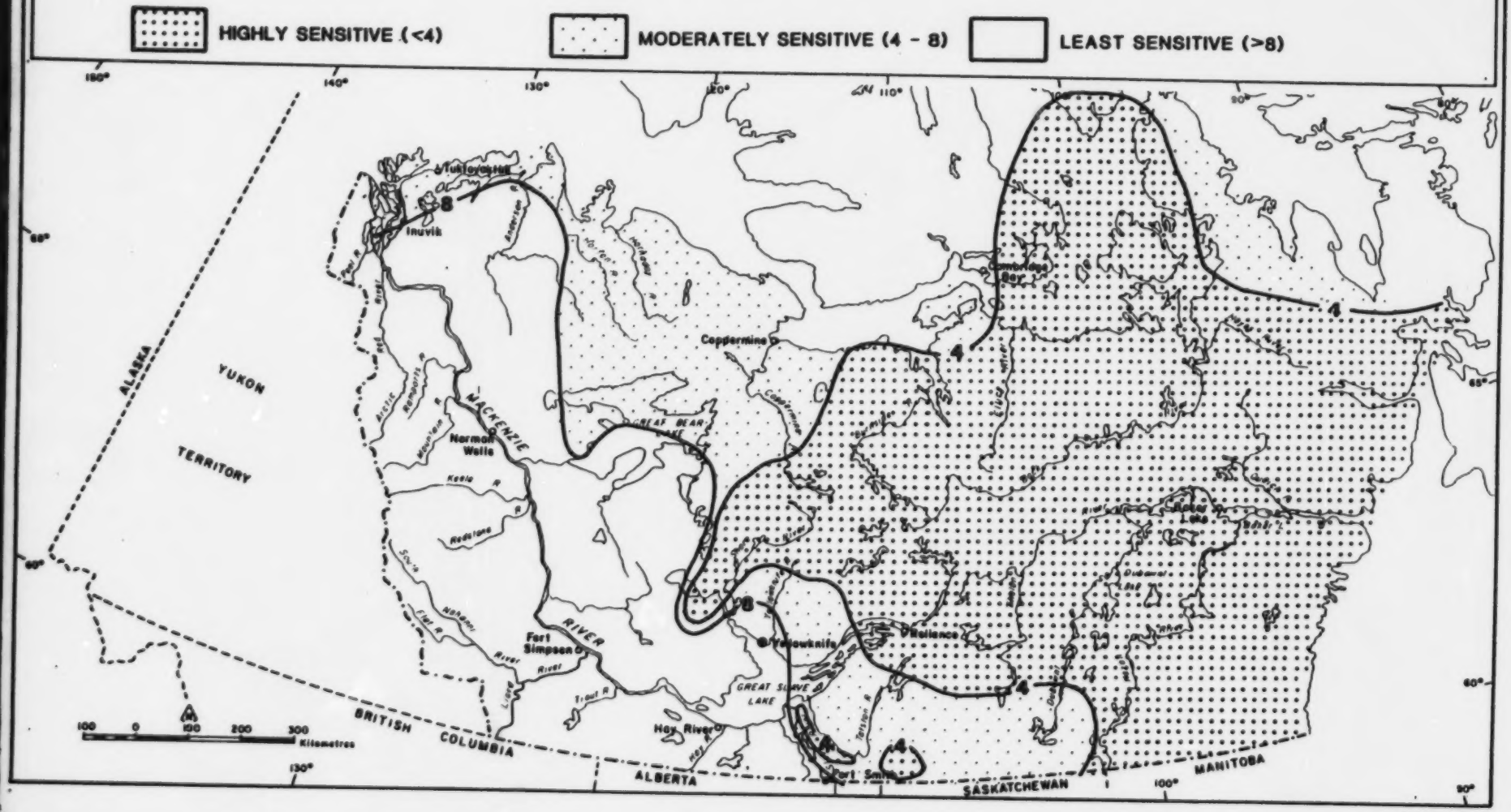
Map 2

NORTHWEST TERRITORIES - MAINLAND BASE MAP

AQUATIC SENSITIVITY OF THE NORTHWEST TERRITORIES TO ACID DEPOSITION

CALCIUM (mg/L)



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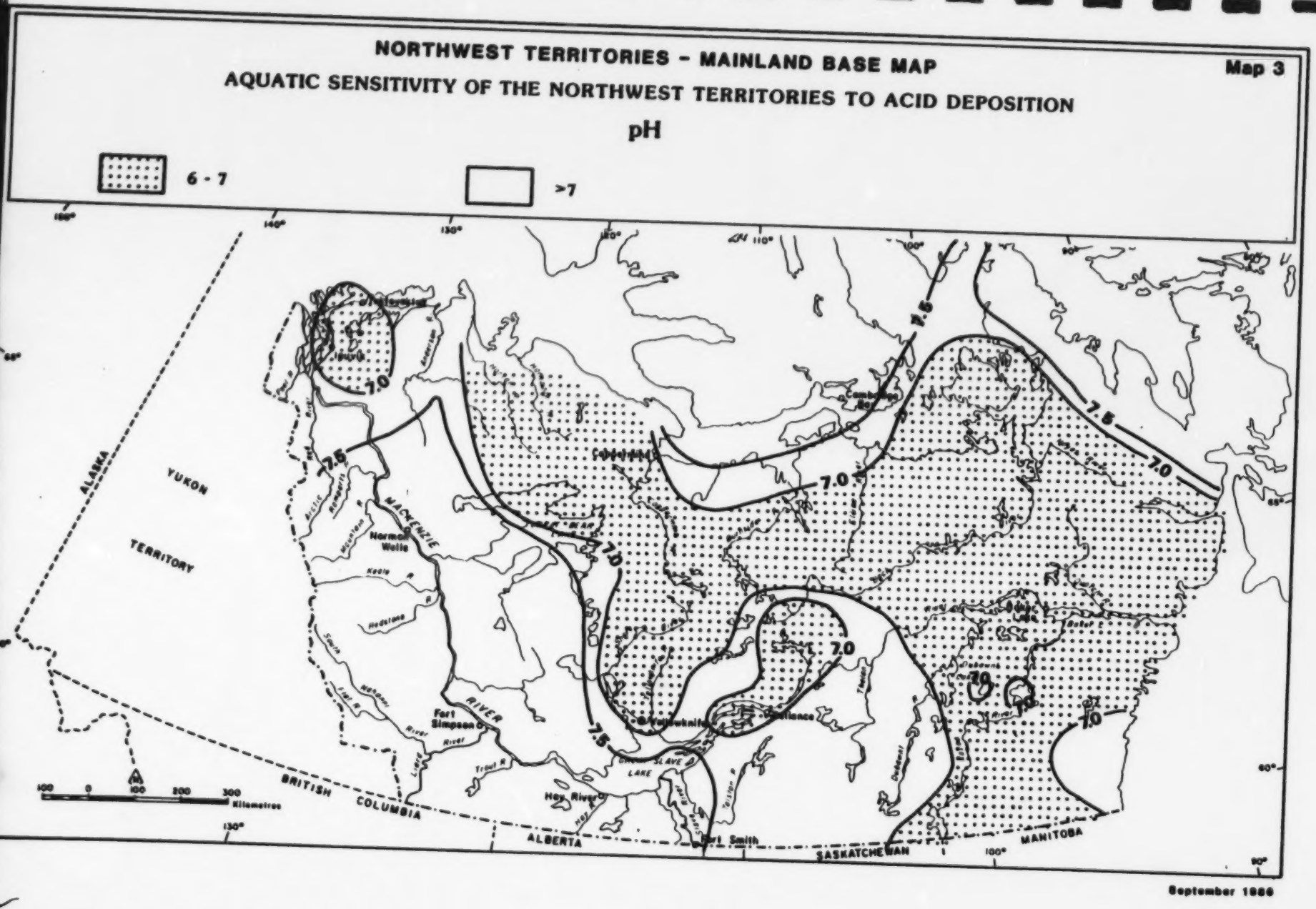
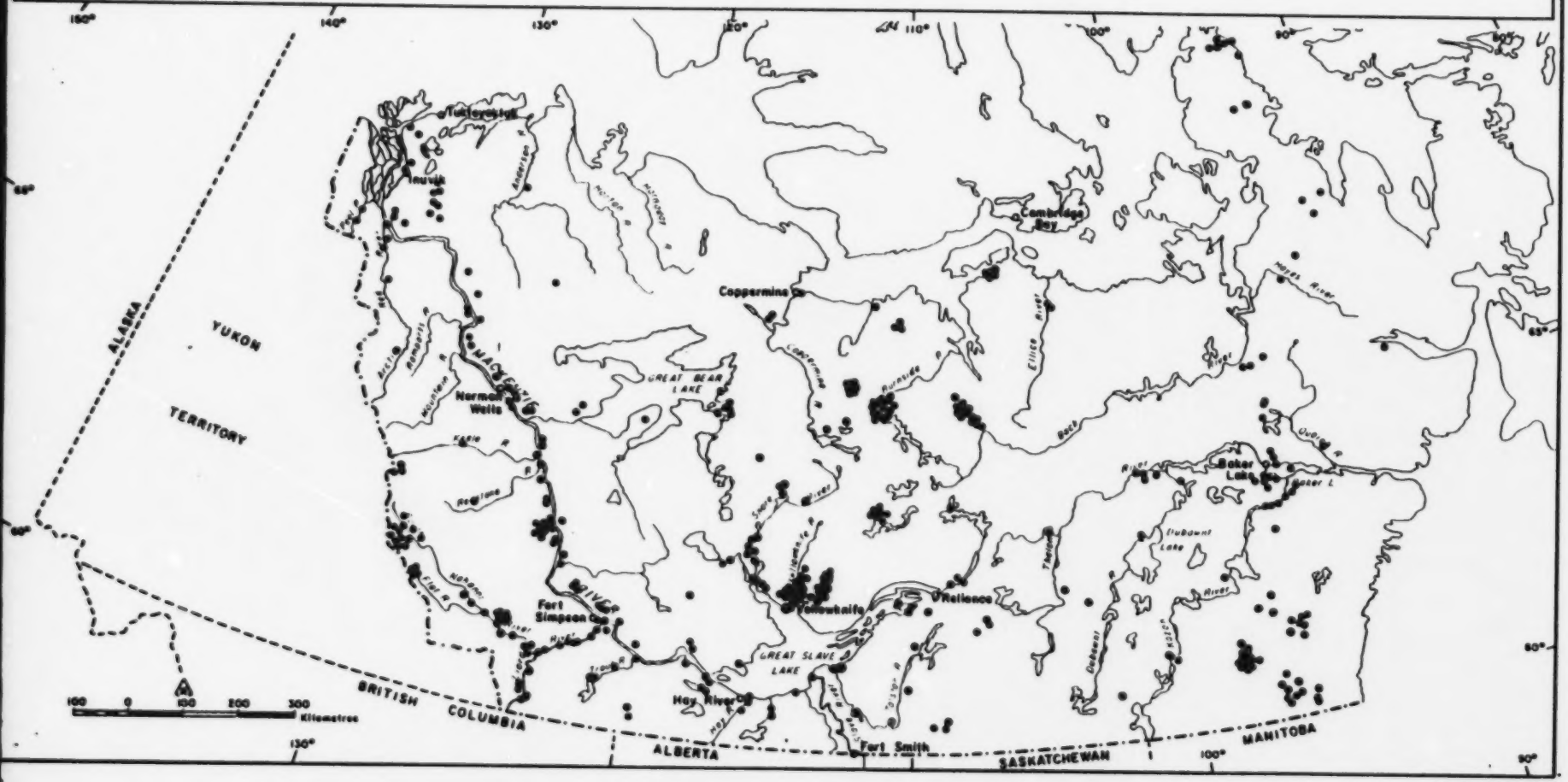

NORTHWEST TERRITORIES - MAINLAND BASE MAP
Map 3
AQUATIC SENSITIVITY OF THE NORTHWEST TERRITORIES TO ACID DEPOSITION
pH
6 - 7
>7
7.0
7.5
YUKON TERRITORY
ALASKA
MACKENZIE
Norman Wells
Fort Simpson
RIVER
Hay River
Fort Smith
Yellowknife
Great Slave Lake
BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
100 0 100 200 300 Kilometres
September 1986

Map 4

NORTHWEST TERRITORIES - MAINLAND BASE MAP
AQUATIC SENSITIVITY OF THE NORTHWEST TERRITORIES
SAMPLING SITES



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